



Title	Mode perturbations of a ring resonator for wideband and multiband filters
Author(s)	Sun, S; Zhu, L
Citation	The 31st URSI General Assembly and Scientific Symposium, Beijing, China, 16-23 August 2014.
Issued Date	2014
URL	http://hdl.handle.net/10722/201200
Rights	URSI General Assembly and Scientific Symposium. Copyright © IEEE.

Mode Perturbations of a Ring Resonator for Wideband and Multiband Filters

Sheng Sun^{*1} and Lei Zhu²

¹Department of Electrical and Electronic Engineering, The University of Hong Kong, Hong Kong, China
e-mail: sunsheng@ieee.org

² Department of Electrical and Computer Engineering, University of Macau, Macau, China
e-mail: LeiZhu@umac.mo

Abstract

In this paper, we study the mode perturbations of a planar ring resonator for proposal and unified design of wideband and multiband microwave bandpass filters. Compared to a planar quarter-/half-wavelength transmission line resonator, a one-wavelength resonator based on a closed ring structure owns two orthogonal degenerate modes. By introducing a small perturbation along a ring, the two degenerate modes can be excited simultaneously, which can be designed to be either a narrow-band two-pole filter or a circularly polarized antenna. We can further excite and stretch the high-order pairs of degenerate modes, which could be designed to work together with two fundamental degenerate modes for applications in wideband and multiband filters. Different topologies and designs are discussed as examples to provide physical insight into their working principle and to demonstrate their advanced features in applications.

1. Introduction

Planar ring resonators have been widely used in design of various radio frequency (RF) and microwave circuits, including filters, oscillators, mixers, couplers, power dividers/combiners, as well as antennas and frequency selective surfaces (FSS) [1], [2]. Fig. 1 shows the typical configurations for a two-port rectangular ring resonator with two 180° symmetrical feed lines or 90° orthogonal feed lines. By adding the perturbation stubs or notches along the ring, the two degenerate modes or splitting frequencies can be excited simultaneously, which co-exist independently of each other. By introducing the coupling quantity between two degenerate modes, a class of dual-mode bandpass filters could be designed with a high-quality factor and a narrow fractional bandwidth. Recently, the concept of multiple-mode-resonator (MMR) was proposed and well documented in [3]. It utilizes the multiple resonances of a single line resonator to form a wideband passband response. In comparison with those resonant modes allocating for multiple passbands, the first few resonant modes can also be combined together to constitute a wide passband. For a ring resonator, the perturbation stubs might be installed along the symmetrical plane and further enlarged so as to split these interested resonant frequency modes [4-6]. For example, a triple-resonance ring resonator can be achieved by shifting the first two even-order resonances down to be quasi-equally located at two sides of the first odd-order resonance. Recently, the first two resonances are also utilized to design a multifunctional power divider with a wide passband response [7]. On the other hand, the two fundamental modes and higher-order degenerate modes of a single ring resonator could be excited to design a multi-band bandpass filter [8, 9], while the first few resonant modes of two embedded ring resonators work together for dual-band operations [10, 11].

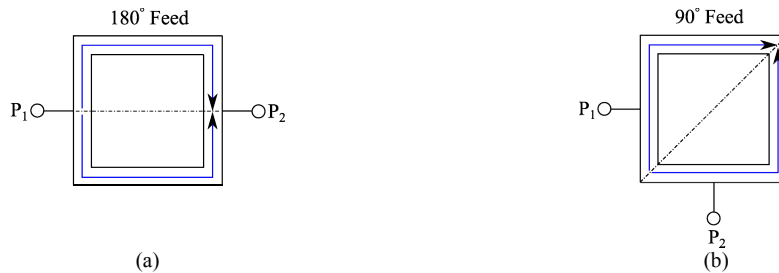


Fig. 1. Configurations of two-port rectangular ring resonators with (a) 180° symmetrical feeding ports and (b) 90° orthogonal feeding ports.

In this paper, the mode perturbations of a ring resonator will be revisited. Based on the full-wave simulation, the current distributions for the first few resonances are first studied. Then, the working principle of the multiple-mode-ring resonator is explained and briefly discussed through the recent design examples using the ring resonators.

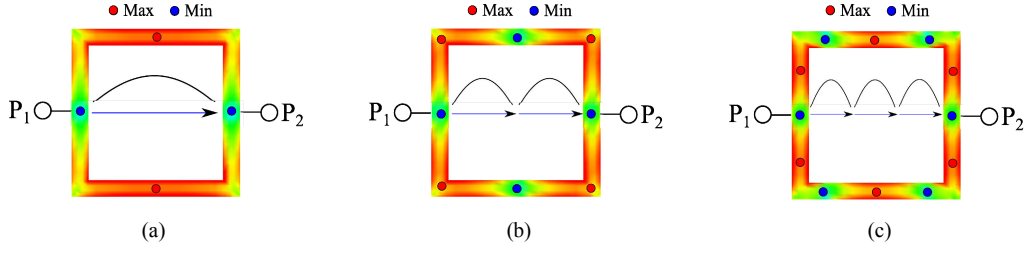


Fig. 2. Current distributions of first three frequency modes in a two-port ring resonator, which is excited by 180° symmetrical feed lines. (a) The first-order mode. (b) The second-order mode. (c) The third-order mode.

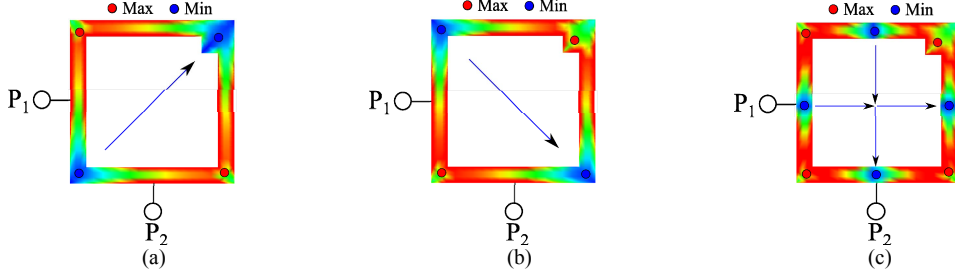


Fig. 3. Current distributions of first three frequency modes in a dual-mode ring resonator, which is excited by 90° orthogonal feed lines. (a) and (b) are for the first pair of odd modes with splitting frequencies, and (c) is for the first even mode with overlapped mode frequency.

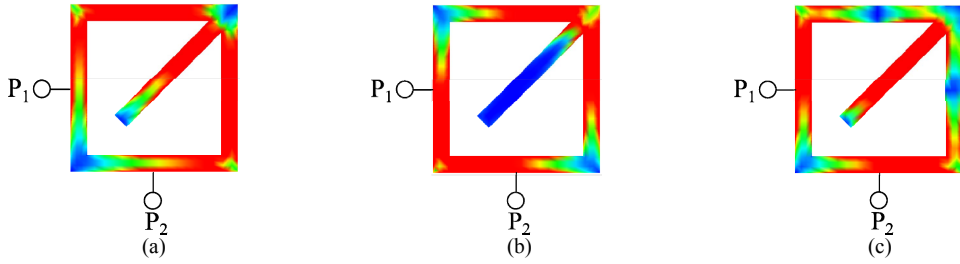


Fig. 4. Current distributions of first three frequency modes in a multi-mode ring resonator, which has a long perturbation stub.

2. Mode Perturbations of Ring Resonator

Fig. 2 shows the current distributions of the first three resonant modes of a two-port ring resonator excited by 180° symmetrical feed lines. Without any perturbations, the upper and lower paths exhibit the same current distributions for both of these modes, which imply that the two frequency modes are overlapped with each other. By observing the maximum and minimum locations of these current flows, both of them behave as the current standing waves. There are various perturbation approaches to split these resonant modes. Among them, installing stubs or notches are the most commonly used approach to perturb the microstrip ring resonators [1]. As shown in Fig. 3, the small squared patch element is installed at the upper-right corner (45°) of the ring, which is excited by 90° orthogonal feed lines. In this case, the dual-mode can only be observed at odd modes (Fig. 3(a) and Fig. 3(b)) instead of even modes (Fig. 3(c)). In other words, the even modes might not be perturbed because of the weak coupling between two degenerate modes or zero voltage locations along the ring resonator. However, by further stretching the perturbation stub as shown in Fig. 4, one of the first high-order degenerate modes can be excited and shifted to lower frequency due to the longer length. At the same time, one of the fundamental modes (Fig. 4(a)) can also be perturbed and shifted to lower frequency, while another one is hardly perturbed as shown in Fig. 4(b). Therefore, it is theoretically possible to allocate the three degenerate modes equally distributed in a certain frequency range.

Without loss of generality, we consider two perturbation stubs to be installed along the symmetrical plane (at 45° and 225°) as shown in the inset of Fig. 5(a). When the lengths of two installed stubs are equal to each other, i.e. $L_1 = L_2$, the first few resonant frequencies can be perturbed by adjusting the stub length except the second resonant frequency. As mentioned above, this resonant mode at the second resonance cannot be perturbed by these two stubs. Similar situations will also happen in the unbalanced perturbations when the lengths of two perturbing stubs are not equal, as shown in Fig. 5(b) for $L_1 = L_2/2$ and Fig. 5(c) for $L_1 = L_2/3$. It is interesting to notice that the perturbing effect of

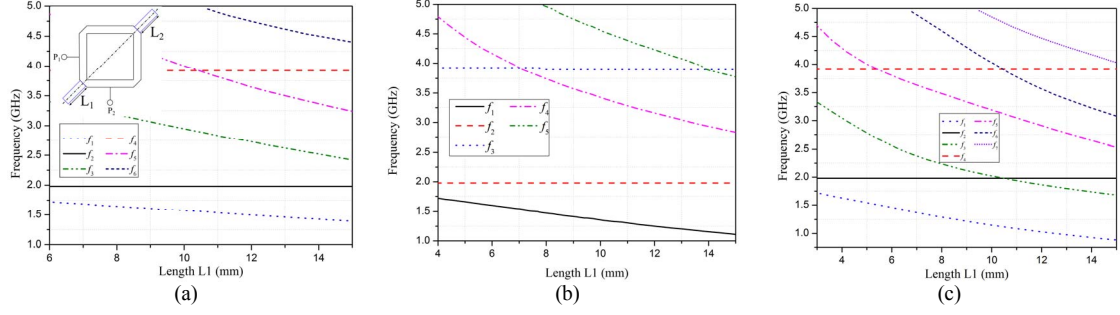


Fig. 5. The first few resonant frequencies versus the lengths of the perturbing stubs at 45° and 225° . (a) $L_1 = L_2$; (b) $L_1 = L_2/2$; (c) $L_1 = L_2/3$.

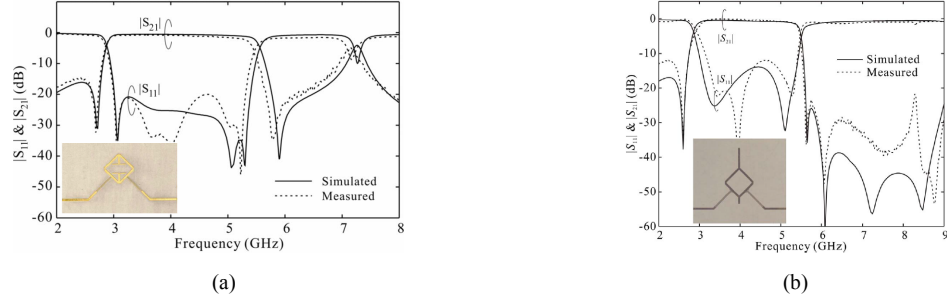


Fig. 6. Wideband bandpass filters using the first three resonant modes when (a) $L_1 = L_2$ [4]; (b) $L_1 = L_2/3$ [6]. Substrate: RT/Duroid 6010 with $h = 0.635$ mm and $\epsilon_r = 10.8$.

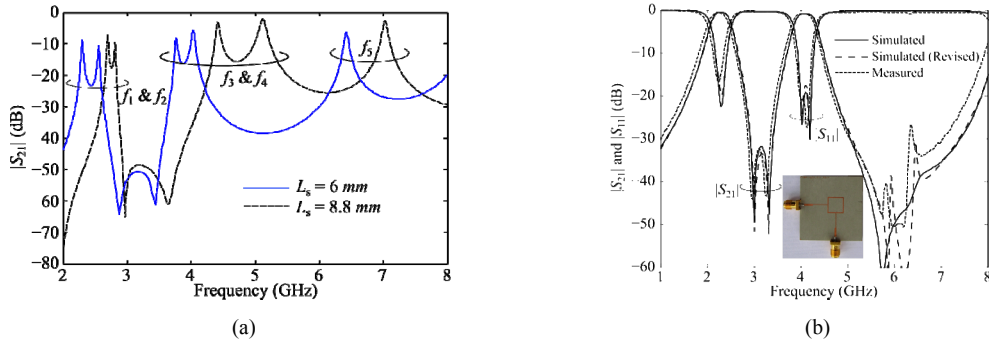


Fig. 7. (a) Frequency responses of the ring resonator under the weak coupling with different coupled-line lengths (L_s). (b) Photograph, simulated and measured results of a dual-band ring-resonator bandpass filter [9]. Dimensions: $L_s = 9.0$ mm, $g_1 = g_2 = 0.1$ mm, $L_c = 8.9$ mm. Substrate: RT/Duroid 6010 with $h = 1.27$ mm and $\epsilon_r = 10.8$.

unbalanced cases is enhanced with fast frequency shifting. In particular, for the first resonance f_1 , the slope of solid-line in Fig. 5(b) is larger than the slope of dot-line in Fig. 5(a). These properties can be utilized to better allocate the resonant frequencies for design of a wideband or multi-band bandpass filter.

3. Design Examples and Discussions

As studied above with the design graphs plotted in Fig. 5, the first three resonant frequencies can be quasi-equally allocated by properly changing as the length of perturbed stubs. As a result, these three resonant modes can be utilized together to form a wide passband. Fig. 6(a) shows a photograph, the simulated and measured results of the fabricated wideband filter for the case of $L_1 = L_2$ [4]. In this example, the first three resonant modes are utilized and a wide bandpass response over the 2.8–5.7 GHz is achieved. The measured return loss is kept higher than 20.0 dB within the passband. It can also be observed that the fourth resonance is located around 7.2 GHz, which produces a spurious harmonic passband and degrades the upper stopband performance. To suppress it, the unbalanced perturbations might be considered as shown in Fig. 6(b), where $L_1 = L_2/3$ [6]. From the results, two extra transmission zeros are excited above the desired passband, while the first three resonances are allocated into the passband. Both of these measured results have a good agreement with those obtained from the full-wave EM simulation.

On the other hand, the multiband responses can also be achieved by exciting multiple pairs of dual-mode resonances at different frequencies. As shown in Fig. 7, by applying the effects of 90° bending discontinuities along the two paths and the coupled-line sections installed at two orthogonal ports, the second passband can be constructed by a second-order degenerate mode at f_3 and one of the third-order degenerate modes at f_4 . Hence, without installing any additional perturbation stubs or notches along the ring, two transmission poles can be realized in both two passbands. In addition, because of the two current flow paths of a ring resonator, the number of transmission zeros is more than that in the quarter-/half-wavelength line resonators, which may be further used to improve the out-of-band rejection.

4. Conclusion

The multiple resonant ring resonators with multiple pairs of two degenerate modes have been extensively studied and used for design of the wideband and multiband bandpass filters by properly reallocating the resonant frequencies. By installing the perturbation stubs along the rings, these modes including the fundamental pair and high-order pairs of degenerate modes can be well utilized to form either a wide passband or a multiband bandpass filter. The concept of multiple resonant modes can be expected to be further extended for other applications, such as multifunctional passive components and antenna designs.

5. Acknowledgments

This work was supported in part of HKU seed funding (201111159201, 201209160031) and GRF (716112, 716713), and in part of SRG2013-00043-FST, University of Macau.

6. References

1. K. Chang and L. -H. Hsieh, *Microwave ring circuits and related structures*, 2nd Edition, John Wiley & Sons, Inc., 2004.
2. M. Makimoto and S. Yamashita, *Microwave resonators and filters for wireless communication: theory, design, and application*, Springer-Verlag Berlin Heidelberg New York, 2001.
3. L. Zhu, S. Sun and R. Li, *Microwave Bandpass Filters for Wideband Communications*, 1st Edition, John Wiley & Sons, Inc., Feb. 2012.
4. S. Sun and L. Zhu, "Wideband microstrip ring resonator bandpass filters under multiple resonances," *IEEE Trans. Microw. Theory Tech.*, vol. 55, no. 10, pp. 2176-2182, Oct. 2007.
5. S. Sun, L. Zhu, and H. -H. Tan, "A compact wideband bandpass filter using transversal resonator and asymmetrical interdigital coupled lines," *IEEE Microw. Wireless Compon. Lett.*, vol. 18, no. 3, pp.173-175, Mar. 2008.
6. S. Sun and L. Zhu, "Wideband microstrip ring resonator bandpass filter with asymmetrically-loaded stubs," in Asia-Pacific Microwave Conf. (APMC'08), Dec. 16-20, 2008.
7. S. S. Gao, S. Sun, and S. Xiao, "A novel wideband bandpass power divider with harmonic-suppressed ring resonator," *IEEE Microw. Wireless Compon. Lett.*, vol. 23, no. 3, pp. 119-121, Mar. 2013.
8. S. Luo, L. Zhu, and S. Sun, "A dual-band ring-resonator bandpass filter based on two pairs of degenerate modes," *IEEE Trans. Microw. Theory Tech.*, vol.58, no.12, pp.3427-3432, Dec. 2010.
9. S. Sun, "A dual-band bandpass filter using a single dual-mode ring resonator," *IEEE Microw. Wireless Compon. Lett.*, vol. 21, no. 6, pp. 298-300, Jun. 2011.
10. J.-W. Baik, L. Zhu, and Y.-S. Kim, "Dual-mode dual-band bandpass filter using balun structure for single substrate configuration," *IEEE Microw. Wireless Compon. Lett.*, vol. 20, no. 11, pp. 613-615, Nov. 2010.
11. S. Sun, S. S. Gao, and C. C. C. To, "A dual-band dual-ring bandpass filter with large bandwidth ratio," *Electronics Lett.*, vol. 48, no. 25, pp. 1600-1602, Dec. 2012.